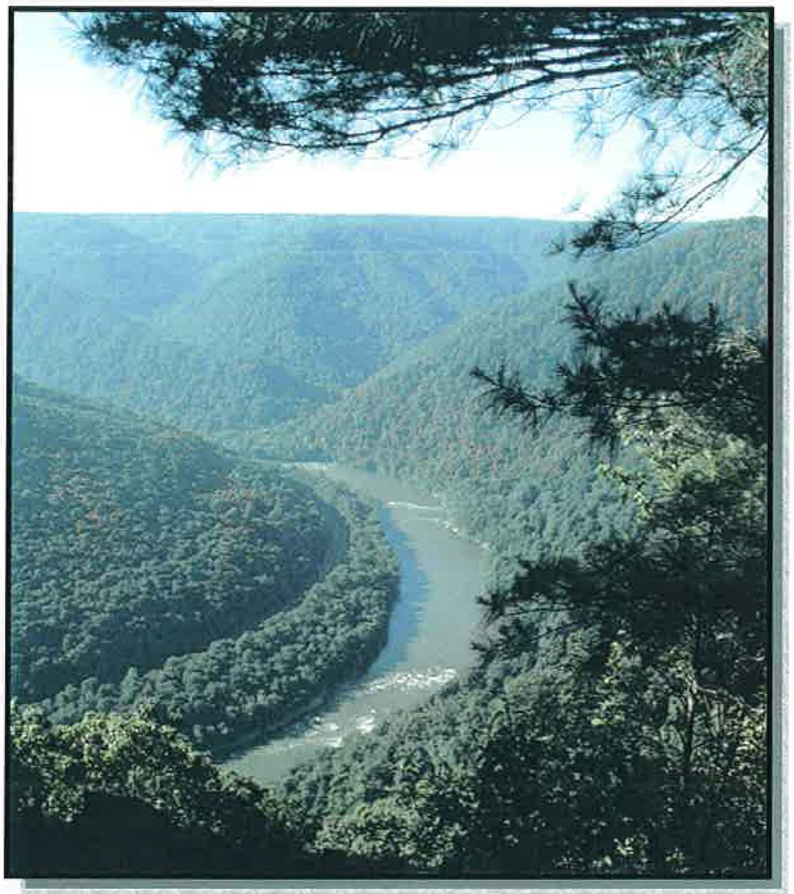
Biological Evaluation of Hemlock Woolly Adelgid at New River Gorge National River, Gauley River National Recreation Area, and Bluestone National Scenic River, West Virginia, July 2007



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ABSTRACT

In the winter of 2007, USDA Forest Service personnel conducted surveys to evaluate hemlock woolly adelgid (HWA), *Adelges tsugae* population densities and to assess the need for treatment at the New River Gorge National River (NERI), the Gauley River National Recreation Area (GARI), and the Bluestone National Scenic River (BLUE). Current populations are building in most areas and are sufficient to impact tree health. Treatments using imidacloprid on accessible, individual, high-valued, infested hemlock trees and the release of natural enemies are recommended in the Burnwood, Fern Creek, upper Wolf Creek, Kaymoor, Grandview, and Kates Branch areas of NERI, Hedricks Creek area of GARI, and on the west side of Bluestone River downstream of the Mountain Creek Lodge of BLUE.

INTRODUCTION

HEMLOCK WOOLLY ADELGID

Adelgids are small, soft-bodied insects that feed exclusively on conifers. The family is divided into two genera: *Adelges* and *Pineus*. There are six species of *Adelges* that occur in North America, of which only one is native (Montgomery 1999), the Cooley spruce gall aphid (*Adelges cooleyi*). This adelgid occurs coast to coast in northern North America. Its primary hosts are recorded as white (*Picea glauca*), blue (*Picea pungens*), Sitka (*Picea sitchensis*), and Engelmann (*Picea engelmannii*) spruce (Baker 1972). It has an alternate host, Douglas fir (*Pseudotsuga menziesii*). There are 10 species of *Pineus* that occur in North America, of which seven are native. Four of these the pine bark adelgid (*Pineus strobi*); the pine leaf adelgid (*P. pinifoliae)*; the red spruce adelgid (*P. floccus*); and the spruce gall adelgid (*P. similes*) seem to be indigenous to eastern North America (Drooz 1989, Montgomery 1999). These species attack eastern white pine (*Pinus strobus*), red spruce (*Picea rubens*), and black spruce (*Picea mariana*) but seldom cause extensive damage (Drooz 1989, Montgomery 1999). Little is known about the population dynamics, ecological role, or the predator complex associated with these native adelgids.

Native to Japan, the hemlock woolly adelgid (*Adelges tsugae)* is a pest of eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*T. caroliana*) (Onken et al. 1999), both of which are considered highly susceptible to the adelgid, with no documented resistance (Bentz et al. 2002). The latter tree species is found only in the southern region of the Appalachian Mountains (Onken et al. 1999). HWA is currently established in 17 eastern states from Georgia to Maine, and tree decline and mortality have increased at an accelerated rate since the late 1980s. For example, in the Shenandoah National Park (SNP), hemlock crown health has declined since the early 1990s. In 1990, greater than 77 percent of the hemlocks sampled were in a "healthy" condition; by 1998, less than 10 percent were in a "healthy" condition (Akerson and Hunt 1998). In another study at

SNP, tree mortality significantly increased from an initial 8 percent in 1990 to nearly 50 percent in 2000 (Bair 2002). As of 2005, hemlock mortality at SNP was almost 95 % (Onken and Souto 2006). In New Jersey twelve years after initial HWA infestations, tree mortality reached more than 90% in some hemlock stands (Mayer et al 2002).

The hemlock woolly adelgid is parthenogenetic (an all-female population with asexual reproduction) that has six stages of development: the egg, four nymphal instars, and the adult, and two generations a year on hemlock. The winter generation, the sistens, develops from early summer to midspring of the following year (June-March). The spring generation, the progrediens, develops from spring to early summer (March-June). The generations overlap in mid to late spring.

The hemlock woolly adelgid is unusual in that it enters a period of dormancy during the hot summer months. Prior to dormancy, the nymphs produce a tiny halo of wool-like wax filaments surrounding their bodies. The adelgids begin to feed once cooler temperatures prevail, usually in October and continue throughout the winter months. As it matures this woolly covering increases in size and becomes more conspicuous. This woolly sac (ovisac) helps protect the insect and its eggs from natural enemies and prevents them from drying out. These ovisacs can be readily observed from late fall to early summer on the underside of the outermost branch tips of hemlock trees.

Figure 1. Hemlock woolly adelgid nymphs in dormancy.

Figure 2. Hemlock woolly adelgid ovisacs (woolly sac).

The ovisacs of the winter generation contain up to 300 eggs, while the spring generation ovisacs contain between 20 and 75 eggs. The hemlock woolly adelgid also has a winged form that is produced by the spring generation. This form must complete part of its life cycle on spruce. The apparent lack of a suitable spruce host for this form in eastern North America results in a substantial loss of adelgids each year (McClure 1992b). Although natural mortality in HWA populations is commonly between 30 to 60 percent (McClure 1989, 1996), the reproduction potential of this insect remains high. Other mortality is generally attributed to two likely causes: 1) an extended period of cold temperatures or rapid temperature changes that coincides with a susceptible period of development for the adelgid, and/or 2) a sufficient loss in the nutritional quality and

quantity of the food source, which is associated with the decline in health and vigor of the host tree (McClure 1996, Onken et al. 1999).

Adelgid feeding can kill a mature tree in about 5 to 7 years (McClure et al. 2001). This tiny insect (~ 1 mm) feeds on all size classes of hemlock, from seedling to mature, old growth tree. The first instar nymphs, called crawlers, search for suitable sites at the base of the hemlock needles, and insert their feeding stylets into the young hemlock twigs. Once settled the adelgid is committed to that feeding site throughout the remainder of its development. The mouth parts of the adelgid, the stylet bundle, is more than three times the length of the insect and penetrates deep within the plant tissues. HWA does not deplete nutrients directly by feeding on the sap, but rather by depleting the food reserves from the tree's storage cells (McClure et al. 2001). These food reserves are necessary for the production of new growth in the following year.

Dispersal and movement of HWA during its egg and mobile first instar stages is associated with wind, birds, deer, and other forest dwelling mammals. Humans also move the adelgid during logging and recreational activities and movement of infested nursery stock (McClure 1995). Natural enemies native to eastern North America are not capable of maintaining low-level HWA populations (Van Driesche et al. 1996, Wallace and Hain 1998).

HWA was first reported in the western U.S. in the 1920s (Annand 1924, McClure 2001). HWA populations on western tree species, including western hemlock (*Tsuga heterophylla*) and mountain hemlock (*T. mertensiana*), appear to be innocuous; these tree species are believed to be resistant because little damage has been reported (McClure 2001). Unfortunately, both these trees are of limited value for hybridization and planting due to their poor adaptation to the east coast environment (Bentz et al. 2002). In the East, HWA was first reported in 1951 near Richmond, Virginia. It was considered to be more of an urban landscape pest and was controlled using a variety of insecticides applied with ground spraying equipment. Observations of the adelgid were periodically reported in several Mid-Atlantic States in the 1960s and 1970s but it was not until the 1980s that HWA populations began to surge and spread northward to New England at an alarming rate. By the late 1980s to early 1990s, infestations of HWA were reported to be causing extensive hemlock decline and tree mortality in hemlock forests throughout the East (McClure 2001).

Recent phylogenetic analyses now suggests that HWA in eastern North America likely originated from southern Japan while HWA found in western North America represents a separate lineage (Havill etal. 2006). The standing theory is that HWA found in western North America is native to that region and western hemlocks have co-evolved with this pest. This theory is further supported when we consider that at least one host specific natural enemy, *Laricobious nigrinus*, is also only found in western North America.

HEMLOCK IMPORTANCE

Eastern hemlock is an extremely shade tolerant tree species, capable of surviving for as long as 350 years underneath a shaded forest canopy (Quimby, 1996). It is a slow-

growing long-lived tree. It may take 250-300 years to reach maturity and may live for 800 years or more (Godman and Lancaster 1990). Eastern hemlock forests create distinctive microclimates and provide important habitat for a variety of wildlife, such as birds, fish, invertebrates, amphibians, reptiles and mammals. In the Northeast, 96 bird and 47 mammal species are associated with hemlock forests at some point during their life (Yamasaki et al. 2000). Hemlocks create a cooling effect in summer that is a critical factor in supporting trout populations. Studies have shown that removal of hemlock trees within 80 feet of a stream can cause temperatures to rise 6 to 9 degrees Celsius (Lapin 1994).

NERI, GARI, BLUE are USDI Park Service sites located in Fayette, Raleigh, Summers, Mercer, and Nicholas counties in West Virginia and cover 72,189 acres, 11,507 acres, and 4,310 acres, respectively. Hemlock trees are a common component of the plant community at these three parks and form almost pure stands along many of the narrow high-gradient stream corridors and are co-dominant canopy trees on 10,190 acres. Old growth hemlock stands ranging between 100 and 200 years old are scattered throughout these parks and there are a couple that are approaching 300 years old at GARI (Perez 2005).

Hemlock forests provide significant contribution to the ecological, recreational, and aesthetic values of these parks. Many waterfalls and wetlands are associated with hemlock forests and recreational activities such as hiking, trout fishing, bird watching, general "sight-seeing", and picnicking are very popular and concentrated in these areas. Rare bird species including Swainson's warbler, blue-headed vireo, Cerulean warbler and Louisiana waterthrush are found only in areas where hemlock is a major component of the plant community.

MONITORING AND MANAGEMENT ACTIVITIES

In 1999, the NPS established a long-term hemlock forest monitoring program (Perez, 2005). Thirty-six 400m^2 sampling plots were selected in GARI and NERI hemlock stands. No plots were established at BLUE due to logistical constraints. The objective of the study was to gather information on hemlock health, HWA infestation levels, biodiversity, and rare, threatened and endangered species.

HWA was first detected within the park boundaries along the Bluestone River in 2000 (Perez, 2000). By 2005, HWA was found in 8 of the 36 monitoring plots (22%) at NERI and GARI. Trees along the Bluestone River have been infested the longest, and currently exhibit declining tree health.

In 2007, the park established a Cooperative Agreement with West Virginia University to resample all of the vegetative parameters including a bird survey. This will be the first comprehensive inventory since the plots were established in 1998. A final report is expected in spring 2008.

In 2003, the park initiated a HWA management program, and funding and technical assistance has since been provided by the USDA Forest Service. Program goals include:

- Educate the visiting public and neighbors about HWA and the threat to the hemlock forest through a variety of media including newspapers, television, internet, and park sponsored interpretive programs.

- Inventory and monitor long-term trends within the hemlock ecosystems, and document the effects of HWA on biological diversity and hemlock decline.

- Implement a suite of integrated pest management alternatives to mitigate the effects of HWA on the ecosystem including the use of biological and chemical controls.

- Continue to encourage and support research efforts to increase the knowledge and understanding of the ecological significance of the native hemlock forests.

The objectives of the suppression program are:

- Protect public health and safety in areas of the park with high visitor use, such as, picnic areas, overlooks, campgrounds, roads, and trail heads, through the reduction of hazardous trees created by the dead and dying hemlock trees.

- Preserve hemlock stands with large numbers of sensitive species where treatments are economically feasible and accessible to the public. Select a few exemplary hemlock stands and try to protect them in perpetuity.

- Protect federally protected species, hemlocks along high quality streams, and old growth forests where feasible.

Figure 3. John Perez, Biologist from NERI releasing *Scymnus sinuanodulus* beetles in May 2007.

Biological Control: Since 2005, the park, with assistance from the USDA Forest Service in Morgantown, WV, has been releasing predatory beetles in hemlock forests that contain outstanding resource values and located in areas inaccessible or impractical for chemical treatments. The releases have included *Laricobius nigrinus*, *Sasajiscymnus tsugae*, and *Scymnus sinuanodulus* predatory beetles (Table 1). Monitoring of the beetle release effort has been conducted by the US Forest Service and *Laricobius nigrinus* has been confirmed to be established at the Hedrick's Creek release sites.

Figure 4. *Laricobius nigrinus* beetle recovered at Hedrick's Creek in Fall 2006.

Table 1. Predatory beetle releases at New River Gorge National River and Gauley River National Recreation Area.

Species	Number Released	Release Location	Date of Release	Number Recovered/Date
L. nigrinus	300	Hedrick's Creek (GARI)	11/05	5 adults/ fall 2006, 1 adult/ spring 2007
S. tsugae	5,118	Wolf Creek (NERI)	5/06	None to date
S. tsugae	5,000	Burnwood (NERI)	5/06	None to date
L. nigrinus	310	Hedrick's Creek (GARI)	12/06	1 adult/ spring 2007
L. nigrinus	146	Burnwood (NERI)	12/06	None to date
S. sinuanodulus	500	Upper Wolf Creek (NERI)	5/07	None to date

Chemical Control: In March 2003, NPS personnel treated 33 trees at Grandview using a soil injection of imidacloprid (Merit®).

In 2006, the park employed the services of a three person crew from the West Virginia Citizens Conservation Corps to conduct chemical treatments. Park personnel and the WVCCC crew received training from USDA Forest Service personnel before beginning treatments. Areas selected for treatment included the Fern Creek, Grandview, Glade Creek and the Bluestone River areas. Soil injections using the Kioritz soil injector with Merit 75WSP were conducted between May and June and again in September and October on 1,474 hemlock trees. Stem injections using the Arborjet "Tree IV" system and Imajet insecticide were conducted in June on 59 hemlock trees. The average tree diameter breast height was 13 inches.

Figure 5. Chemical treatment using the Arborjet "Tree IV" system using Imajet insecticide.

SURVEY AREAS

Survey areas at the parks were chosen by NPS resource management staff based on ecological significance and/or visual importance. Hemlock at NERI is an important component of the forest canopy on about 5,990 acres (about 7%) of the total park acreage. The seven areas at NERI surveyed included Burnwood Area, Fern Creek, upper Wolf Creek, Kaymoor Mine Trail, Grandview, Kates Branch, and Glade Creek.

Burnwood is a 100 acre day use area located across from the Canyon Rim Visitor Center. This area is utilized for educational school trips and is the location of the Laing Loop Nature Trail.

Fern Creek has one of the more dense hemlock stands at NERI. The Endless Wall Trail, located in the Fern Creek area, is 2.4 miles long providing great views of the New River Gorge, and access to some of the best known climbing locations in the parks. A large portion of the stand is within a riparian zone. Breeding populations of the Swainson's warblers have been documented at Fern Creek, and the rare green salamander is known to occur there as well.

At Wolf Creek, hemlock trees are a dominant component of the forest and many trees range between 80 and 195 years old. Breeding populations of the rare Cerulan and Swainson's warbler, along with rare amphibians and the Allegheny woodrat occur in this area.

The Kaymoor area has a hiking trail that descends steeply to the abandoned Kaymoor Mine and provides a great overlook of the river and gorge.

Grandview has four developed overlooks with outstanding vistas and has a high visitor use. There are five trails ranging from 3/8 to 2 ½ miles in length. Hemlocks frame the vistas and are a major component of the rare rimrock forest community in this area. The rare Allegheny woodrat has been documented within the hemlock forests.

The Kates Branch area borders the largest wetlands complex (approximately 20 acres) at NERI. Hemlocks contribute to the ecological integrity of this wetland and the Kates Plateau Trail follows an old logging road through this area.

At Glade Creek there is a 5.6 mile trail that follows an abandoned railroad. The creek has good to excellent water quality and a diverse ecosystem. The area is known for its waterfalls and as a popular trout stream.

Hemlock stands at GARI are an important component of the forest canopy on about 4,000 acres (about 35% of the total park acreage). The GARI contains hemlock stands designated as "Outstanding Natural Feature" having "high intrinsic or unique values" in the park's General Management Plan (1997). The area surveyed for HWA populations at GARI was in the Hedricks Creek area. This area has old growth hemlock trees averaging 199 years old and some trees approaching 300 years old.

At BLUE the hemlock forests occur on about 200 acres (5% of the total park acreage). Populations of the federally threatened Virginia spiraea are found in the understory along the banks of the Bluestone River. The Bluestone River has good to excellent water quality and diverse aquatic ecosystems. The survey area was along the west side of the Bluestone River on a 3 mile section of the Bluestone Turnpike Trail, downstream of the Mountain Creek Lodge. Hemlock trees found along the floodplain and side tributaries contribute to the scenery and ecological function of this wild and scenic river.

METHODS

The hemlock woolly adelgid sampling plan was used to evaluate HWA populations in hemlock stands by assessing the percentage of infested trees (Costa and Onken, 2006). This sampling plan measures the infestation level of the stand rather than individual trees and does not involve laborious counting of HWA. By rapid examination of branches on 8 to 100 trees, HWA infestations can be characterized and as few as 2 percent of infested trees can be detected with 75 percent reliability. The cutoff threshold used to stop sampling is based on optimum sample sizes to obtain a relative precision level of 0.25 percent (Table 2).

Table 2. Maximum number of trees that must be examined to detect an infested tree by minimum detection threshold (minimum percent of infested trees) and reliability level (probability of finding a single infested tree). The shaded area encompasses the recommended 100-tree sample. (Costa and Onken, 2006)

Minimum % Infested Trees in Stand	Reliability Level (%)			
	50	75	95	99
0.5	138	277	598	919
1	69	**138**	298	458
2	34	**69**	148	228
3	23	46	98	151
5	14	27	58	90
10	7	13	28	44
20	3	6	13	21

Each stand surveyed was divided into four blocks and the first tree was arbitrarily selected in the first block of the stand. Selected trees had two branches that could be reached, if possible, but a second branch on an adjacent or nearby tree was acceptable. A branch was selected and closely examined for the presence or absence of white woolly masses (old or new) within the terminal meter of the foliage. If HWA was found on the first branch, it was recorded and the second branch was not surveyed. If no woolly masses were observed on the first branch, then the second branch was examined. The data recorded is a running tally (sum) of the number of trees positive for HWA presence (figure 6).

The next tree was determined by randomly selecting a direction that would provide coverage in that block and pacing out approximately 25 paces (2 steps per pace) to the next sample tree, and the survey process was repeated. In the first block, up to 25 trees would be surveyed if the stop threshold was not reached. The survey would begin again in block two, and again up to 25 trees (50 trees total) surveyed, and if the threshold was not reached, then this process was repeated in blocks 3 (75 trees total) and 4 (100 trees total). When the tally count reached the corresponding threshold, then the survey stopped, or when 100 trees were sampled, which ever came first.

In addition to the stand level assessment, qualitative information regarding HWA densities on individual trees was also collected. On each branch, HWA densities were visually classified on each branch sample as heavy, moderate, light or none based on an estimated percentage of tips with adelgid present as follows:

Heavy (H) = >50% infested
Moderate (M) = 25% to 50% infested
Light (L) = <25% infested
None (N) = 0% infested

A GPS (global positioning system) unit was used to collect coordinates (decimal degrees, WGS84) and map the area surveyed within each park. A GPS point represented the general area of each stand.

To determine the percentage of HWA winter mortality, hemlock branch samples were collected from the majority of the survey areas and brought back to the lab for inspection of live and dead HWA.

Figure 6. Example of the hemlock woolly adelgid sampling plan data sheet used at New River Gorge National River, the Gauley River National Recreation Area, and the Bluestone National Scenic River, 2007.

Site/Location:				**HWA density**	**Scale density**
GPS Locations: B1				**N, L**<25%	**N, L**<1 scale/needle
B2	**B3**	**B4**		**M**=25-50%	**M**=1 scale/needle avg
Date:				**H**>50%	**H**=multiple scale/needle
Surveyor(s):				**Comments:**	

Path Direction	Tree	Sum HWA Trees	STOP > Threshold	Visual Estimate HWA	SCALE	Path Direction	Tree	Sum HWA Trees	STOP > Threshold	Visual Estimate HWA	SCALE
Block 1	1		n/a			Block 3	51		12		
NE	2		n/a			NE	52		12		
SE	3		n/a			E	53		12		
N	4		n/a			S	54		12		
NW	5		n/a			SE	55		12		
SW	6		n/a			SE	56		12		
S	7		n/a			S	57		13		
S	8		8			W	58		13		
SE	9		8			NW	59		13		
SW	10		8			S	60		13		
W	11		8			NW	61		13		
S	12		8			NE	62		13		
E	13		8			W	63		13		
E	14		8			NW	64		13		
NE	15		8			N	65		13		
SE	16		8			NE	66		13		
NE	17		8			NE	67		13		
E	18		8			W	68		13		
N	19		9			N	69		13		
NW	20		9			N	70		13		
N	21		9			E	71		13		
W	22		9			SE	72		13		
S	23		9			NE	73		13		
W	24		10			SE	74		13		
W	25		10			SW	75		13		
Block 2	26		10			Block 4	76		13		
E	27		10			N	77		13		
SE	28		10			E	78		13		
NE	29		10			N	79		13		
SE	30		10			SE	80		13		
NE	31		11			SW	81		13		
E	32		11			S	82		13		
N	33		11			SW	83		13		
N	34		11			S	84		13		
SW	35		11			W	85		13		
W	36		11			N	86		13		
SW	37		11			W	87		13		
NW	38		11			W	88		13		
NW	39		11			NE	89		13		
NE	40		11			N	90		13		
N	41		12			N	91		14		
SW	42		12			NW	92		14		
W	43		12			N	93		14		
NW	44		12			SE	94		14		
SW	45		12			NE	95		14		
W	46		12			N	96		14		
SE	47		12			E	97		14		
S	48		12			SE	98		14		
E	49		12			E	99		14		
S	50		12			NE	100		14		

RESULTS

A total of nine areas were survey within NERI, GARI, and BLUE: Burnwood area, Fern Creek, upper Wolf Creek, Kaymoor area, Grandview, Kate's Branch, Glade Creek, Hedricks Creek, and Bluestone River. The survey areas are represented in Figures 7a-b, and a summary of the results is presented in Table 3.

All survey areas reached a STOP threshold at eight trees within the first block of the stand indicating the percentage of infested trees is 100 percent. HWA densities within tree were observed to range from very light to heavy among the survey areas.

Winter HWA mortality ranged from 45-95 percent within the parks. The greatest mortality occurred at Wolf creek (95%), Kaymoor (85%), and Grandview (82%). All three of these sites are located on the north-facing rim of the New River Gorge, where the wind, compounded with cold winter temperatures may have contributed to the higher mortality rates.

In general hemlock conditions range from healthy to light decline within most of the survey areas, with exception of Bluestone River, where decline symptoms are more prevalent and range from light to severe decline.

Table 3. Summary of HWA survey data collected in winter/spring, 2007 at NERI, GARI, and BLUE.

Location	# Trees Surveyed	STOP Threshold	Visual Estimate[1] HWA Range	Estimated Percentage of Winter HWA Mortality
Burnwood Area (NERI)	8	8	L-H	63
Fern Creek (NERI)	8	8	L-H	no samples collected
Wolf Creek (NERI)	8	8	L	95
Kaymoor (NERI)	8	8	L-M	85
Grandview (NERI)	8	8	L-H	82
Kate's Branch (NERI)	8	8	L-H	46
Glade Creek (NERI)	8	8	L-H	45
Hedricks Creek (GARI)	8	8	L-H	68
Bluestone (BLUE)	8	8	L-M	no samples collected

[1]HWA infestation densities were designated by visually inspecting each branch sample based on an estimated percentage of tips with adelgid present and categorized as follows:

Heavy (H) = >50% infested
Moderate (M) = 25-50% infested
Light (L) = <25% infested
None (N) = 0% infested

Figure 7a. Hemlock woolly adelgid survey locations at New River Gorge National River, the Gauley River National Recreation Area, and the Bluestone National Scenic River, winter/spring, 2007.

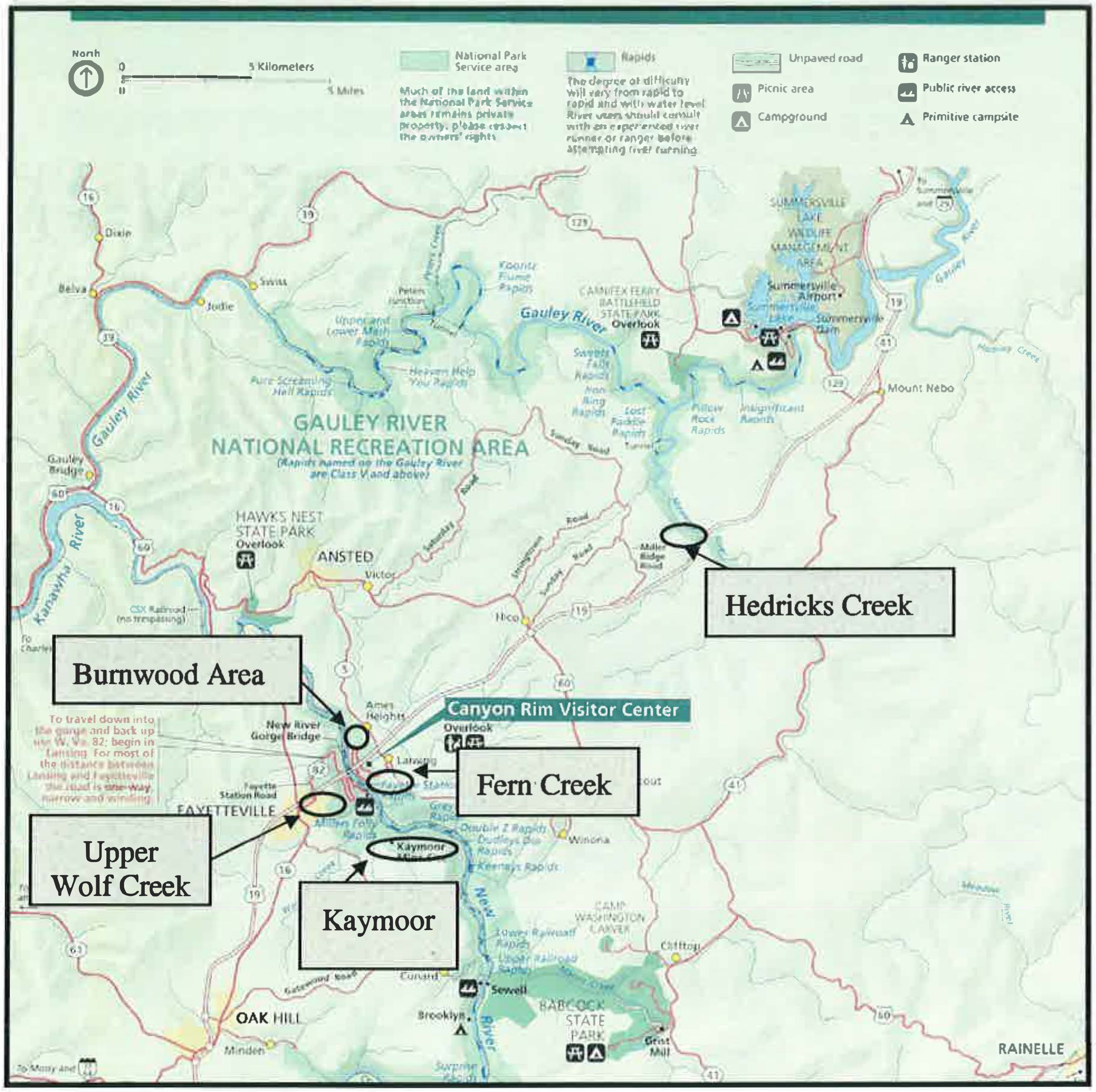
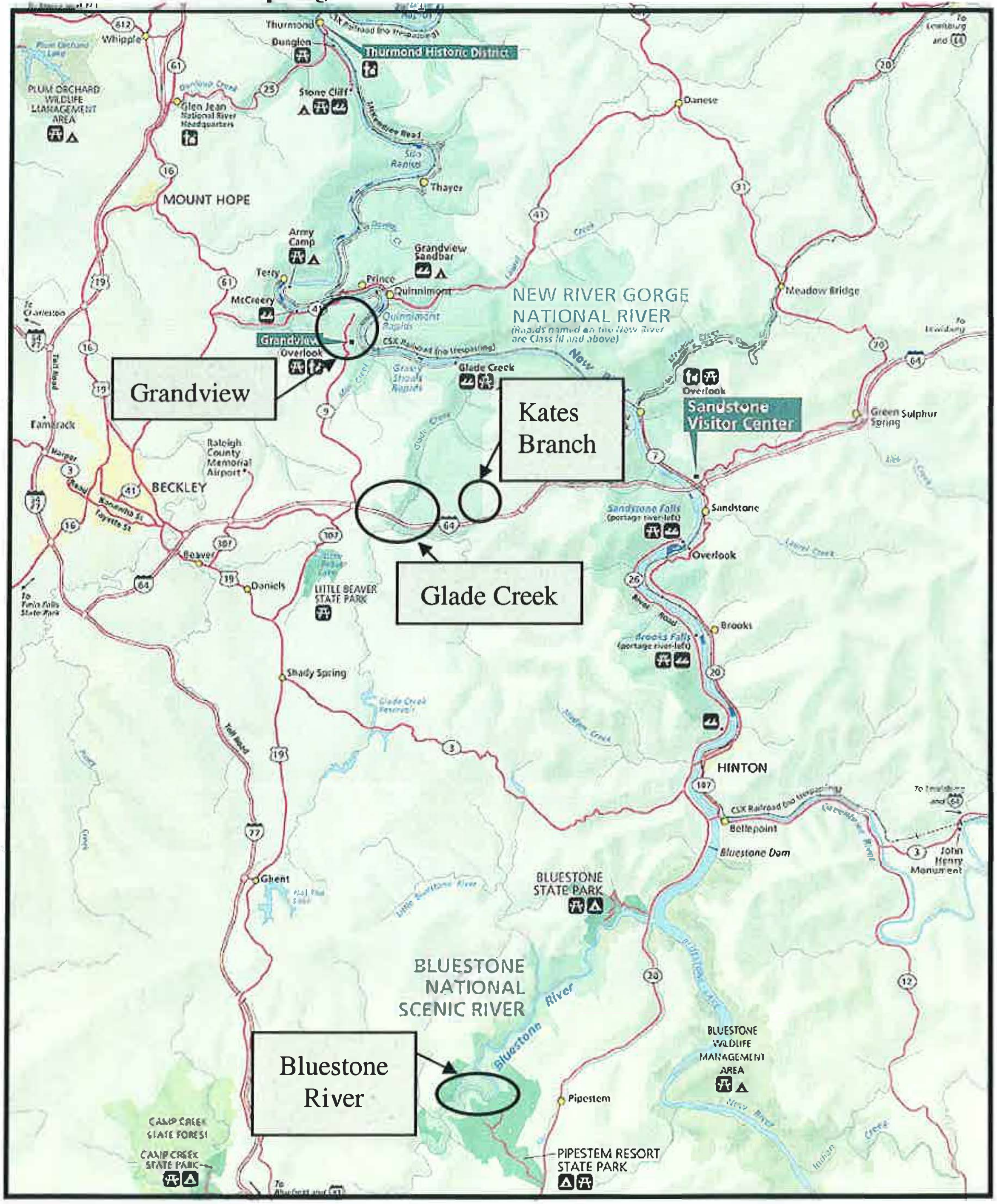


Figure 7b. Hemlock woolly adelgid survey locations at New River Gorge National River, the Gauley River National Recreation Area, and the Bluestone National Scenic River, winter/spring 2007.



DISCUSSION

HWA populations are generally low to moderate throughout most of the survey areas. HWA densities are highly variable between trees, ranging from none to heavy, but all sites have an established population. There was a noticeable difference between the HWA survey conducted in 2005 and the survey conducted this year in that HWA populations are much more prevalent throughout the survey areas. Predicting year to year changes in HWA densities is difficult because of the dynamic nature of the many variables involved. Factors such as future climatic conditions, changing micro habitat (tree and site) conditions and other biotic and abiotic factors affect both survival and fecundity of HWA. However the pattern of abundance and distribution is conducive to outbreak populations when conditions are favorable. Consequently, impacts to hemlock resources throughout NERI, GARE, and BLUE will continue to increase.

Management Considerations

Chemical management options for protecting hemlock stands are limited by the biology and feeding behavior of HWA, pest population densities, site conditions (i.e. proximity to streams), accessibility and limited application technology currently available. Insecticide treatments although effective, are conducted on an individual tree basis which can be both labor intensive and costly. Thus treatment strategies are typically focused in high value sites such as recreational or scenic areas or where hemlock stands have an important ecological role or genetic preservation is a high priority. Classical biological controls such as predators and pathogens are being pursued by the USDA Forest Service but will likely take years to become effectively established. As such, preservation of hemlocks in the short term will require intensive monitoring and periodic chemical treatments when infestations are discovered.

Foliar chemical treatments. Aerial spray using horticultural oil or insecticidal soap is not an option because aerial sprays could not provide the needed "saturation" necessary to ensure that the insecticide adequately covers the insect. Aerial spraying with more toxic insecticides (e.g. malathion or diazinon) would have very significant, unacceptable impacts on a wide range of non-target insects and other animals and limited control benefits (Evans 2000). Application of insecticides using ground spraying equipment is generally limited to areas accessible to hydraulic spray equipment and areas where over spray or run off would not contaminate streams, lakes or ponds. Backpack sprayers could be effectively used for foliar treatment of infested seedlings and saplings to protect regeneration.

Systemic Insecticides. Several systemic insecticides are labeled for adelgids and can be injected (e.g. imidacloprid, bidrin or Metasystox-R®) or implanted (e.g. acephate) into hemlock trees. Imidacloprid is by far the most common systemic insecticide being used to control HWA and is applied as a soil drench or injected into to the soil around hemlock trees. These insecticides are absorbed and trans-located by the vascular system of the tree to feeding adelgids and will effectively suppress HWA populations (Doccola et al. 2003, Webb et al. 2003, Evans 2000, Steward and Horner 1994, McClure 1992a). Soil

injection in sandy or saturated soils should be avoided as leaching of imidacloprid into the soil profile and groundwater (McAvoy et al. 2002) is a possibility. Soil injections immediately adjacent to creeks or other open waters and areas prone to frequent flooding should be avoided. Imidacloprid formulated as a trunk injection is available under the trade names Pointer®, IMA-jet® and Imicide® and are labeled for tree injection for the control of adelgids. Both stem and soil treatments of imidacloprid have become the preferred treatment for HWA in high value hemlock stands by state and federal resource managers. A further discussion of this product follows.

Imidacloprid is a relatively new insecticide in the family of chemicals called neonicotinoids (Felsot 2001) in the chloronicotinyl subgroup (USDA Animal and Plant Health Inspection Service 2002). It has a mode of action similar to that of the botanical product nicotine, functioning as a fast-acting insect neurotoxicant (Schroeder and Flattum 1984) that binds to the nicotinergic receptor sites in the postsynaptic membrane of the insect nerve (USDA Animal and Plant Health Inspection Service 2002), mimicking the action of acetylcholine, and thereby heightening, then blocking, the firing of the postsynaptic receptors with increasing doses (Schroeder and Flattum 1984, Felsot 2001). Because imidacloprid is slowly degraded in the insect, it causes substantial disorder within the nervous system, leading in most cases to death (Mullins 1993, Smith and Krischik 1999).

Imidacloprid is considered to have low to moderate mammalian toxicity (Mullins 1993), largely because it does not bind nerve receptors in mammals sufficiently to trigger nervous activity (Felsot 2001). The selective toxicity of imidacloprid is perhaps best illustrated by its use in flea treatments approved for cats and dogs. Advantage® is applied directly to the animal's skin; this preparation carries very little, if any, risk to the animal or to the people, including children, who may handle the animal (USDA Animal and Plant Health Inspection Service 2002). Chronic (repeated dose) toxicity studies have demonstrated that imidacloprid is not carcinogenic and is not mutagenic and demonstrates no primary reproductive toxicity (Mullins 1993). In studies of metabolic fate in rats, imidacloprid was rapidly absorbed and eliminated in the excreta (90 percent of the dose within 24 hours) with little bioaccumulation (0.5 percent of the dose after 48 hours) and no biologically significant differences occurring between sexes, dose level, and route of administration (USDA Animal and Plant Health Inspection Service 2002). Imidacloprid is an insecticide exhibiting both systemic and contact activity. The spectrum of activity primarily includes sucking insects (aphids, whiteflies, leaf and plant hoppers, thrips, plant bugs, and scales), many Coleopteran species, and selected species of Diptera and Lepidoptera. Activity has also been demonstrated for ants (Hymenoptera); termites (Isoptera); and cockroaches, grasshoppers, and crickets (Orthoptera). No activity has been demonstrated against nematodes or spider mites (Mullins 1993). In spider mites, imidacloprid has been demonstrated to cause an egg-laying enhancement (James and Price 2002). Since spider mites can be a problem in ornamental hemlocks, open-grown imidacloprid-treated trees should be carefully monitored for increases in mite populations.

Little is known about the biotransformation and bioactivity of the metabolites of imidacloprid in hemlock. What is known is that trunk-injected imidacloprid generally requires a week or longer to provide adelgid control, with protection lasting for up to 2 years (Tater et al. 1998, Silcox 2002). The soil injection or soil drench methods of imidacloprid treatments can take several months for translocation to occur but typically has provided better consistency in treatment efficacy and is expected to provide control for at least 3 years. Stem injections should not be used on severely stressed trees.

***Biological control*:** There are no known parasites of adelgids. There are three predatory beetles approved for release and each is unique in its dispersal, reproductive potential, feeding behavior, and suitable climate regimes. They are all very host specific. Where these natural enemies are released is the responsibility of state forest health specialists from each state and the USFS. All of the releases are in infested hemlock stands found primarily along the leading edge of the generally infested area, where hemlocks are still healthy and HWA densities have not yet overwhelmed the trees. The release and establishment of HWA natural enemies is not likely to provide short term control of HWA. It is considered to be a long term approach and will likely require a complex of natural enemies to maintain HWA below damaging levels. It may be years before these predators can self perpetuate sufficiently before any level of success can be determined.

The first predator beetle to be imported and released for biological control is a tiny, black lady beetle, *Sasajiscymnus tsugae*, from Japan. Since 1995, over 1.5 million *S. tsugae* beetles have been released in over 200 sites in 16 eastern states from Georgia to Maine. The recovery of *S. tsugae* beetles in the years following release have been sporadic. The number of beetles recovered have rarely been more than one or two per site. Adult beetles have been captured near some of the release sites more than 6 years after release, and some more than 1/2 a mile from nearest release site.

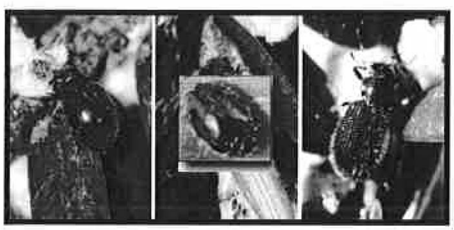


Figure 8. Beetles released for biocontrol (left to right): *Sasjiscymnus tsugae* from Japan, *Scymnus sinuanodulus* from China and *Laricobius nigrinus* from Pacific Northwest.

Another predatory beetle, *Scymnus sinuanodulus*, a lady beetle from China, has been released since 2005. More than 16,000 adult beetles have been released in eight states. So far, few beetles have been recovered from the release sites.

A Derodontid beetle, *Laricobius nigrinus*, from the Pacific Northwest is also approved for release. Mass rearing of this predatory beetle began in 2003, and more than 30,000 beetles have been released in eleven states. Recovery of *L. nigrinus* has been confirmed at most sites. At some release sites, adult beetles are easily found and hundreds of larvae have been recovered.

Release of predator beetles should not take place in close proximity of hemlock trees that have received imidacloprid treatments. Preferred release sites are newly infested sites where trees and adelgids are still healthy. Older infested sites where adelgid densities are low and recovery of hemlock trees is evident has also proven acceptable. Predator

beetles are laboratory reared and the number of predators available in any given year is variable depending in part, on the success of the rearing facilities to locate good quality host material for a food source. Artificial diets are not yet available.

RECOMMENDATIONS

Systemic insecticide treatments using imidacloprid are recommended for HWA control on accessible, individual, high-valued, infested hemlock trees within the parks. The continued release and establishment of *Sasajiscymnus tsugae, Scymnus sinuanodulus,* and *Laricobius nigrinus* predatory beetles is also recommended in infested areas of the park that are not in close proximity to chemical treatments.

Where possible, soil treatments are preferred over stem injections as they are less costly, offer more consistency in treatment efficacy and longer protection. Imidacloprid applied at 0.75 grams of a.i. per inch of trunk diameter (dbh) is recommended for the soil injections, and treatment timing should be in the spring or fall. The insecticide recommended for stem injections is IMA-jet® at 5% active ingredient with the number of application sites on the tree determined by dbh. Criteria for number of application sites is as follows: 4 application sites for 6-16 inches dbh, then add one additional application site for each additional 4 inches of dbh. Hemlocks tend to have faster uptake of the stem injected insecticides in the mornings during the spring and fall months when cooler temperatures and higher humidity prevail.

Imidacloprid treated trees should be marked in a manner that will identify the year they were treated, such as a basal spray of color coded paint or tags since theses treatments should provide at least 2-3 years of control and treatments on neighboring trees in subsequent years may be desirable.

With treatment options comes the potential for non-target effects; land managers must balance the risk of these effects with the potential benefits that come with the control of the HWA. As a best management practice, the USFS has previously recommended that hemlocks within 50 feet of open water be treated with a stem injection rather than a soil treatment. Research at the CT Agricultural Research Station has recently demonstrated that imidacloprid binds tightly with organic soils such that movement more than a few centimeters is unlikely when the chemical is placed in the organic layer of the soil. Imidacloprid will leech through mineral soils quite readily and it is critical applicators use good judgment as to placement of the injector tip in organic soils which in most cases, is less than 3 inches deep. This depth also coincides with the shallow feeder roots of eastern hemlock. With this new research information, soil treatments closer to open water may be acceptable when treatment decisions are based on the soil conditions surrounding each tree to be treated within the 50 foot buffer. In circumstances where rocky porous soils exist or the organic layer is not sufficiently deep enough to handle the injector tip placement, trees should be treated using a stem injection system. Ground spraying using horticultural oil to protect hemlock seedlings and saplings by means of a

backpack sprayer should be considered in areas where protecting younger hemlocks is desirable and where over spray or run off would not contaminate streams, lakes or ponds. One or two applications of a 2% solution of horticultural oil applied in early summer or early fall is recommended as adelgids have not yet developed the wool covering that can impede penetration of the insecticide.

Resource managers should continue to annually monitor tree health conditions, adelgid population densities and treatment efficacy. It is not logistically or economically feasible to chemically treat all trees in numerous or large hemlock stands. Therefore, resource managers must prioritize treatment areas and select individual, accessible, high valued, infested hemlock trees for treatment.

Predatory beetle releases take place in the spring or fall of the year when HWA are actively feeding. The establishment of these natural enemies offers potential long-term control and may minimize the need for repeated chemical treatments in future years. The release of HWA natural enemies within the park should continue.

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File Code: 3400
Date: July 16, 2007

Calvin F. Hite, Superintendent
New River Gorge National River
USDI National Park Service
PO Box 246
104 Main Street
Glen Jean, WV 25846-0246

Dear Mr. Hite:

Enclosed is a biological evaluation of hemlock woolly adelgid (HWA) at New River Gorge National River (NERI), Gauley River National River (GARI), and Bluestone National Scenic River (BLUE). A total of nine areas were surveyed including portions of the Bluestone River at BLUE, Hedrick's Creek at GARI, and Burnwood Area, Fern Creek, upper Wolf Creek, Kaymoor, Glade Creek, Grandview, and Kates Branch areas at NERI.

The majority of the hemlocks were found to be in good health, with the exception of BLUE where hemlock trees continue to exhibit signs of decline. All surveyed sites have established HWA populations although densities are variable within all three parks. Impacts to hemlock resources are expected to increase without continued management intervention.

We recommend chemical treatment using imidacloprid via. soil or stem injections as appropriate on accessible, high-valued individual hemlock trees, based on the management objectives of the parks. In less accessible hemlock stands we encourage the release of HWA natural enemies, as they become available.

Chemical treatment will provide short-term (at least 2 years) control on individual trees and may need to be retreated in subsequent years until natural enemy populations become established and begin to provide long range control of HWA.

Please contact Brad Onken (304)-285-1546 or Karen Felton (304)285-1556, if you have any questions concerning this report.

Sincerely,

Bob Lueckel

ROBERT LUECKEL,
Field Representative, MFO

Enclosure

Cc: John Perez, Biologist, NERI
Linda Drees, NPS, IPM Program Coordinator
Clark Haynes, WVDA
Jerry Boughton, AO